Soggy Breakdown of Apples and Its Control by Storage Temperature

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POMOLOGY SECTION

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SUMMARY

1. Soggy breakdown, a non-parasitic disease which develops at low temperatures, is described.
2. Soggy breakdown is distinguished from "internal breakdown" and from "physiological decay" or the breakdown which accompanies senescence. The name "mealy breakdown" is suggested for the latter.
3. Grimes and Wealthy apples have been found to be very susceptible to soggy breakdown, while Jonathan, Arkansas, Willow and Northwestern Greening appear immune to the disease.
4. The initial appearance of soggy breakdown on Grimes in cold storage occurred during the early part of December.
5. Differences of 2° or 4° F. in cold storage temperatures markedly affected the development of the disease.
6. No serious amount of soggy breakdown occurred on the fruit stored at 36° F., or on fruit held in common storage. The disease did not appear in common storage.
7. Soggy breakdown developed most seriously at 30° F., as compared to its development at 32°, 34° and 36° F. The most satisfactory temperature for the storage of Grimes was found to be 36° F.
8. When stored immediately after picking, late picked fruit was more susceptible than early picked.
9. Delayed storage materially increased the susceptibility to soggy breakdown. The influence of delayed storage, however, appears to be linked with the time of picking.
10. Exposure of the fruit to free circulation of the storage room atmosphere prevented the development of soggy breakdown on delayed storage fruit during one storage season, and caused visible shriveling of the fruit.
11. Direct access of the fruit to air during delayed storage did not reduce development of the disease in storage.
12. Evidence obtained suggests that apples become susceptible to soggy breakdown after certain periods of exposure to ordinary temperatures.
13. Soggy breakdown appeared to be more serious some years than others.

14. Grimes from the Wenatchee apple district of Washington and those from central Michigan were as susceptible to soggy breakdown as Grimes from Iowa.
15. Grimes in commercial cold storage developed as much soggy breakdown as those at the same temperature in experimental storage.
16. The quality, condition and attractiveness of Grimes, stored at 36° F., were superior to those stored at the lower temperatures.
17. Grimes stored at 36° F. softened only slightly more than those at lower temperatures.
18. An increase in the tendency to apple-scald in Grimes, due to a slightly higher storage temperature, was successfully averted by the use of oiled paper wraps.
19. With well graded, high quality fruit, the increase in loss due to apple rot fungi at 36° F. was insignificant.

Soggy Breakdown of Apples and Its Control by Storage Temperature

By H. H. Plagge and T. J. Maney*

Published experimental data and numerous recorded observations show that certain varieties of apples sometimes "hold up" better in common or air-cooled storage than under cold storage conditions with the temperature as low as 32° F. thruout the storage period. In the apple storage investigations of the Pomology Section it has been observed that Grimes usually begin to "go down" prematurely when stored at 32° F. Each season this variety has become seriously affected with what had been termed internal breakdown. This condition occurred at a time when Grimes normally should be in its prime. This trouble sometimes was extensive enough to make it more important than apple-scald. Previous experiments by the writers (29) show that internal breakdown is not always conditioned by over maturity or by degree of ripeness due to difference in time of picking and delay in storing. The first report of the occurrence of the soggy breakdown on Grimes when stored at the usual cold storage temperatures was made by Plagge (30). The data presented indicated that the disease was caused by a temperature too low for the life processes of the apple to continue normally. Records for a series of years indicate that this breakdown can be better controlled by changing certain conditions of storage, such as temperature, humidity and aeration, than by alternating conditions during the harvest period.

Further experiments on the effect of storage temperature grew out of the fact that apples had been known to keep longer in common storage houses than in cold storage, altho the temperature average was considerably higher in the common storage. The main differences between common and cold storage conditions are temperatures and amount of ventilation. While it is generally recognized that apples keep best at 30° to 32° F. in cold storage, varietal characteristics have some influence. All apple varieties possibly should not be stored at the same temperature. The optimum storage temperature for certain varieties may be slightly above 32° F.

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This report was postponed until sufficient evidence could be obtained to verify the fact that two types of breakdown may occur in apples, and that low temperature, other than freezing injury, is the cause of one of these types. The present report was also postponed in order that the effect of seasonal conditions and locality might be noted.

In its cold storage investigations the Pomology Section uses varieties important in Iowa and centers most attention on varieties commonly affected with such functional diseases as apple-scald, soft-scald, internal breakdown and Jonathan-spot. The principal varieties which have been under investigation include Jonathan, Grimes, Wealthy, Northwestern Greening, Arkansas, Golden Delicious and Willow Twig. Willow Twig was selected because of its excellent keeping qualities. While Grimes and Wealthy have been found to be very susceptible to soggy breakdown, Jonathan, Northwestern Greening, Arkansas and Willow Twig appear to be immune to the disease. However, some of the latter varieties sometimes become severely affected with soft-scald, a disease which will be considered in another publication. The question of variety susceptibility to soggy breakdown has been largely reserved for further investigations. It seems certain that other varieties will be found to be affected by this disease.

At least one exception to the recommended practice of storing all varieties at the same temperature, is the Yellow Newtown which is grown in the Pajaro Valley, California. This variety keeps better at a temperature range of 37° to 40° F., than at lower temperatures. Data from investigations with storage temperature for apples indicate that the present recommended cold storage temperatures are too low, at least for certain varieties.

REVIEW OF LITERATURE

Beach and Clark (2) pointed out that certain varieties of apples showed peculiar deterioration behavior in cold storage. They noted that different varieties were apt to become mealy, while others were apt to burst. Varieties varied in endurance to heat before going into storage. Grimes were reported as being much affected by heat after being picked and before going into storage, while Jonathan was placed in a class of varieties that stand heat comparatively well. According to Beach and Clark, the general practice at that time was to store long keeping varieties at 31° to 32° F., while varieties that did not keep so well were held at 33° to 34° F., altho there was a difference of opinion among storage operators regarding temperature.

The investigations of Powell and Fulton (32) indicated that storage temperatures of 31° to 32° F. were preferable to those

of 35° to 36° F. These investigators state, "The apple keeps longer in a lower temperature, it scalds less, the fruit rots and molds are retarded to a greater extent while the quality, aroma, flavor and other characteristics are fully as good." Present cold storage temperature recommendations have not changed materially from those stated by Powell and Fulton.

Magness, Diehl and Haller (22) recommend that apples from almost all sections of the United States should be held in cold storage at 30° to 32° F.

Recently a questionnaire, sent out by the writers to many cold storage concerns in the United States, revealed that the present practice is to store apples close to the 30° to 32° range.

Sorauer (34) interpreted certain types in the deterioration of fruits as due to unusual conditions of climate and culture, such as deficiency in moisture, high temperature and effect of light sandy soils. He suggested that mealiness of fruit may depend upon a definite act in the ripening process which has been directed into other channels because of the scarcity of water. He indicated that in normal ripening of fruit there is a winey or doughy condition with a constant advance in oxidation or browning. And, further, intensive oxidation under high temperature conditions may cause a lack of acid.

Greene (12) compared cold storage for the entire season with cold storage early and cellar storage later for various varieties. Grimes scalded under both conditions, although they remained firm until the first of March. Jonathan, removed from cold storage to common storage on November 22, were in as good condition as those kept in cold storage thruout the season.

Ramsey, et al., (33) recognized two general types of decay developing in storage; physiological or natural death decay and fungous or bacterial decays. Physiological or old-age decay is a natural change thru which fruit passes if not otherwise destroyed. Fruit stored at 32° F. was in better condition and could be held for a longer period than that stored at 35 to 36° F. Jonathan was found to vary more in keeping quality than almost any other variety. Grimes was not to be held later than the latter part of December, according to their investigations.

Brooks, Cooley and Fisher (4) stated that breakdown is particularly common on overmature apples. Breakdown is considered a disease when it appears prematurely and is described as a condition that characterizes the end of the life of the apple. In describing this disorder, they state:

"It is characterized by a breaking down and browning of the interior of the apple. The riper side of the apple is often more seriously affected than the greener side and the blossom half worse affected than the stem half. During the earlier stages, the flesh may be found quite moist, but it later becomes spongy and

rather dry and 'mealy.' The skin usually retains its normal appearance, but is sometimes slightly duller and darker, and in the later stages of the disease, frequently cracks outward. The presence of the disease can usually be detected by the spongy softness of the apple."

According to Overholser, Winkler and Jacob (27), internal browning of the Yellow Newtown is almost entirely a cold storage trouble. This disease is common to the Yellow Newtown as grown in the Pajaro Valley district in California, a district having cool and moist climatic conditions during the growing season. Ballard, Magness and Hawkins (1) reported on extensive orchard and storage experiments over a period of four years. They concluded that internal browning was more abundant during years with light crops, on fruit of large size, and from trees fertilized with nitrogen fertilizers. Relative to storage temperature they stated that internal browning apparently does not develop seriously if storage temperatures are held at 36° F. or above. They emphasized the importance of right storage conditions during years of light crops and large sized fruit.

Overholser, Winkler and Jacob (27) and Winkler (36) have published full accounts of studies on internal browning. Overholser, et al., called attention to the fact that apples from the Pajaro Valley have been stored at 36° F. during different seasons since about 1910. They found that considerable browning occurred after February 1, even at 36° F. Further experiments were carried on in which apples were stored at still higher temperatures. In a series of experiments in which apples were stored at temperatures ranging from 30° to 70° F., they found that browning did not occur on fruit at a temperature of 57° F. The small amount of browning which occurred at 40° was not sufficient to lessen the marketable quality of the fruit. The degree of browning was not only more severe at temperatures below 40°, but the development of the disease was more rapid at the lower temperatures. In view of these facts and also because Yellow Newtown is a good keeper at 40° F., these investigators stated that the most promising method for the control of browning is prompt storage at temperatures of 37° to 40° F.

Kidd and West (15) of England have investigated a physiological condition of apples occurring in shipments from Australia. They have named this disorder, "Brown Heart," and describe it as follows:

"Essentially, brown heart is an abnormal condition of the fruit resulting from the death and subsequent browning of parts of the internal fleshy tissue, while the peripheral flesh generally remains sound. In slightly affected apples seen in cross section there are only small patches of brown tissue. These patches are isolated, sharply defined and often numerous. They

may arise in the cortex, in the pith, or in both. They often appear to originate in vascular bundle tissue, especially that of the ten main vascular bundles. If the harmful conditions are severe or prolonged a large portion of the internal tissues of the apple may be killed. Even in such cases the superficial tissue of the apple is often quite normal so that the apple appears to be sound until cut open. The internal dead tissue in such advanced cases generally forms a continuous mass, still, however, being sharply delimited from the living tissue. With experience, one can identify badly affected apples by their characteristic springiness, due to the underlying dead tissue, and sometimes by a dull surface appearance."

Kidd and West found that brown heart developed when apples were stored in atmospheres containing certain percentages of carbon dioxide in the presence of oxygen, which was essential. Below a certain danger limit of carbon dioxide, apples kept without the development of brown heart. However, the danger limit was found to vary for different varieties and at different storage temperatures.

In a later publication these investigators (17) listed internal breakdown of apples along with "internal browning," "soft-scald," "flesh collapse," "Jonathan breakdown" and "physiological decay." They concluded that internal breakdown in many varieties is particularly a disease of cold storage and seldom occurs at ordinary temperatures. They present data showing that internal breakdown occurs earlier and to a more serious extent when apples are stored at 32° to 34° F. than when stored at somewhat higher temperatures. They stated that their results completely confirm those obtained by American workers on investigations of internal browning of Yellow Newtown. They apparently recognized the effect of temperature on internal browning and evidently considered temperature more significant than the inherent susceptibility of Yellow Newtown to browning. However they have not considered fully the effect of climatic conditions on the development of this disease. The present writers consider internal browning of Yellow Newtown as being distinctly different from internal breakdown or physiological decay and different from soggy breakdown as noted by Plagge (30). Jonathan breakdown, as reported in Canada, is likely a type of breakdown similar to that of physiological decay or that due to senility.

Daly (9), in reporting on "Jonathan breakdown" in Canada, stated that picking maturity is the main factor in the prevention of the trouble. He considered Jonathan breakdown identical with "flesh collapse." Results obtained with Jonathan stored at 38° to 40° F. are similar to those obtained by Hartman (13). However, he interpreted his data as showing differ-

ent results from those secured with yellow Newtown in the Pajaro Valley, or from those secured by Kidd and West (17) who found internal breakdown, on varieties other than Jonathan, more serious in cold storage than in ordinary storage. Palmer (28) substantiated the reports of Daly on picking maturity for Jonathan, and pointed out that storage conditions have considerable influence on Jonathan breakdown.

The writers believe that Jonathan breakdown, as reported by Daly (9), Palmer (28) and Hartman (13), is an entirely different disease from the low temperature internal breakdown as reported by Kidd and West (17). The differences noted in the susceptibility of Jonathan to Jonathan breakdown among various sections of America are probably due to dissimilarities in soil, climate and other environmental conditions. Magness, Diehl and Haller (23) recently pointed out that Jonathan, when grown in southern sections and in the Pacific Northwest, becomes a fall variety. Contrasted to this, when grown in short season districts such as in Michigan or New England, it becomes an excellent winter storage variety, being well suited for holding in air-cooled storage. Plagge and Maney (29) have found that internal breakdown was never a factor on Iowa grown Jonathan in cold storage. The differences noted in keeping quality are likely due to locality or climatic conditions.

Kidd and West (17) differentiated closely between brown heart and internal breakdown. They placed "flesh collapse," a disease commonly known in New Zealand (25), in the same category as internal breakdown. This is probably correct since McClelland and Tiller (24), (25) and (26), who have made extensive studies of flesh collapse (26), stated: "While it may never be possible to prove the absolute identity of a functional disease in New Zealand with a similar one in England, it is nevertheless almost certain that flesh collapse is identical with the internal breakdown found by Kidd and West (17) in experimental storage in England, and also known as internal browning in America, (1), (27), (36), and as 'scald' in Australia."

Flesh collapse as reported in New Zealand is doubtless identical with the low temperature breakdown as reported in England, as well as with soggy breakdown as reported by Plagge (loc. cit.). However, internal browning of Yellow Newtown cannot be considered identical with these.

McClelland and Tiller (26) concluded that some change will have to be made in the storage temperature in order to avoid internal breakdown. They also stressed the importance of a lower humidity as a means to reduce further the amount of internal breakdown and suggested differential treatment of apples from different localities and of different varieties for further consideration.

Kidd and West's (17) statement that internal breakdown in many varieties seemed to be particularly a disease of cold storage and that it seldom occurred at ordinary temperatures is in agreement with the results reported by Plagge (loc. cit.). They have noted that internal breakdown with English apples in cold storage varies widely both in external and internal appearance according to the variety, the stage of maturity and other conditions, but that a rather sharp distinction can be observed between scald and all forms of breakdown. Certain points in their description of internal breakdown follow:

"The earliest stage in the development of internal breakdown that can be detected, previous to the definite browning of the tissues, is that at which the flesh assumes a slightly abnormal appearance, which precedes any change in tint. In later stages the feature common to all types of internal breakdown is a marked browning of some part or of the whole of the flesh of the apple. The brown tissue may, or may not, extend to the skin, hence affected apples may show all degrees of external disfigurement. Apples in the final stage of the disease may be completely brown and exhibit a 'baked' appearance. In the early stages of this disease the flesh may be firm and crisp altho brown, but generally in its later stages internal breakdown is accompanied by softening of the flesh tissue so that it can be easily mashed into a paste with one's fingers. Softening of the tissue, however, is not an invariable characteristic of this disease."

In a paper by West (35) taken from the researches of Kidd and West, the author stated:

"While cold storage as compared with ordinary storage has been found as a rule to extend the storage life of the apple, this is by no means invariably the case. In certain cases ordinary storage has proved superior to cold storage, owing to the premature onset at the low temperature of a functional disease known as 'internal breakdown'."

In the 1924 report of the food investigation board in England (11), it is stated that Bramley's Seedling kept more satisfactorily at 32° F. than at 30° F. It is pointed out that a temperature above 34° F. will probably have to be recommended for this variety due to internal breakdown at lower temperatures.

A still more recent publication by Kidd, West and Kidd (18) on the "Gas Storage of Fruit," further indicates that a type of breakdown due to low temperature commonly occurs in apples. The following statement is taken from their report:

"English apples as a rule are not able to complete their normal storage life at average temperatures below a certain level. This minimum average storage temperature level varies with the constitution of the apple in question. It depends upon the variety, the season and the cultural conditions." The tempera-

Fig. 1. Soggy breakdown on Grimes stored at 32° F. Mealiness and bursting of the outer portions of the apple are not characteristic of soggy breakdown.

ture for maximum length of storage life for Bramley's Seedling was found to be 37° F. For King Pippin it was found to be 40° F., while Newton Wonder, which was found to be resistant to the trouble, kept satisfactorily at 30° F.

Haynes (14) determined the acidity of apples at various intervals thru the storage period for fruit held at 1°C. (33.8° F.) and at 15° C. (59° F.). Evidence was obtained which indicated that high acidity and a slow rate of loss of acid are conditions favoring internal breakdown, and that the latter would probably be lessened if apples were not exposed to low temperatures until their acid content was reduced.

Carrick's investigations (7) on the effects of freezing on mature apples, indicated that for Wagner, Baldwin, Rome and Ben Davis the optimum cold storage temperature was 30.2° F. or even somewhat lower. In considering the practical relationship of his studies to cold storage, he assumed that the maximum freezing point of the apple should be the optimum and minimum temperature for apple storage, and that, for safe commercial practice, a temperature as low as 29.3° F. in the coldest parts of the storage house would be desirable. However, he pointed out that some varieties due to certain peculiar defects may require somewhat higher temperatures.

In a later paper (8) on the respiration of apples at low temperatures, Carrick pointed out that a lowering of the storage temperature from 0° C. (32° F.) to —1.5° C. (29.3° F) extends the storage life of Northern Spy and Golden Delicious. However, he noted a physiological disturbance in Baldwin, McIntosh and Rhode Island Greening at the lower temperature, which he considered the same as that reported by Plagge (30).

Investigations by Plagge and Maney (29) with Iowa grown Grimes indicate that internal breakdown is often the result of over-maturity at time of storing and time of picking. This was generally the case, but in certain instances breakdown was

found to occur on fruit appearing to be the least mature at the time of storing.

Plagge (30) reported on the effect of storage temperature upon soft-scald and breakdown of apples in 1924 and presented data showing that a type of breakdown occurred at 30° and 32° F. on Grimes but not at 34°, 36° and 40° F., or, in ordinary storage. Two types of breakdown were described. They were: "soggy breakdown," caused by a too low storage temperature; and "mealy breakdown," recognized as old age decay. Additional investigations conducted during 1925 and 1926 are in agreement with the results for 1924.

DESCRIPTION OF SOGGY BREAKDOWN OF APPLES

In Grimes apples stored at 30° to 32° F., soggy breakdown makes its initial appearance during the middle of December. It occurs more severely at 30° F. than at 32° F. and to a lesser extent at 34° F. than at 32° F. At a temperature of 36° F. or above it has not developed markedly. The following points have been noted in the development of soggy breakdown on Grimes and Wealthy:

The disease begins in the cortical region and can first be detected in cross section as small, light brown areas in tissue adjoining vascular strands. It does not, however, begin at the primary vascular bundles, altho in the later stages tissue adjacent to these may be involved.

The discolored areas vary considerably in size and number, according to the severity of the disease, and may increase in size until considerable portions of the cortical region of the apple are included. If the conditions causing soggy breakdown are prolonged, a complete ring of soft, brown, dead tissue is formed, which may be seen in transverse sections. The affected tissue is sharply defined from the remaining sound white portion of the core region. The proximity of brown tissue to the skin, determines the extent of external discoloration. The more typical specimens show no brown discoloration of the skin and have a white zone of sound flesh near the periphery of the apple, while a considerable portion of the cortical tissue is affected. In such cases the apple appears to be sound until it is cut open. A characteristic sponginess, due to the underlying soft tissue, makes it easy for the experienced observer to detect the disease. Severely diseased fruit usually shows a dull superficial color.

When apples are only slightly affected it is difficult to determine whether or not the disease is present, because the soft areas may be small and deeply seated within the flesh of the apple. Even in cross section the diseased portions, if small, may easily be unobserved, as they may occur near either end of the apple.

Fig. 2. Apparently normal Grimes affected with soggy breakdown.

When the apples are first removed from storage the brown affected tissues are soggy and watery in appearance. The texture is not mealy, but resembles that of certain varieties of apples which, after baking, tend to retain considerable juiciness and firmness. A very distinctive alcoholic taste is noticeable in affected apples, for both discolored and normal tissue. This taste is sometimes noticeable in apples before discoloration of tissue takes place. It may be taken as an indication of the first stage of the disease.

Late in the storage period the formerly sound tissue in affected fruit becomes discolored and mealy. It then resembles tissue of old age decay in apples. Likewise, the affected tissue of diseased fruit becomes mealy and dry. However, the line of

Fig. 3. Sections of apples in fig. 2 showing tissue involved in soggy breakdown.

delimitation between tissue, which was formerly typical soggy breakdown tissue and tissue which was sound in affected apples, can still be observed, due to color differences between the two. (fig. 7).

When soggy breakdown fruit is removed to temperatures higher than that at which the disease occurred, the affected portions shrink and become dry and leathery. If the conditions causing the disease are prolonged, the entire apple may become entirely brown and soggy. A characteristic of the disease is that the core region is the last portion of the fruit to become affected. This feature markedly contrasts the disease from old age decay or "mealy breakdown," in which the initial discolora-

Fig. 4. Mealy breakdown on Grimes showing bursting. The specimen in the center at the top is without external discoloration; the two apples on each side show considerable brown discoloration.

tion takes place within the core line. Small fruit is as susceptible to the trouble as large fruit.

DESCRIPTION OF MEALY BREAKDOWN OF APPLES

As the name implies, mealy breakdown is that type of functional disorder in apples in which the texture of the flesh changes from a hard firm juicy condition to a soft, dry and mealy consistency. It is characterized, also, by the terms old age decay, physiological decay, internal breakdown and senescence. It is usually associated with fruit held too long in storage or at too high a storage temperature.

Apples which have reached the senescent period frequently show bursting of the skin and of the outer or peripheral por-

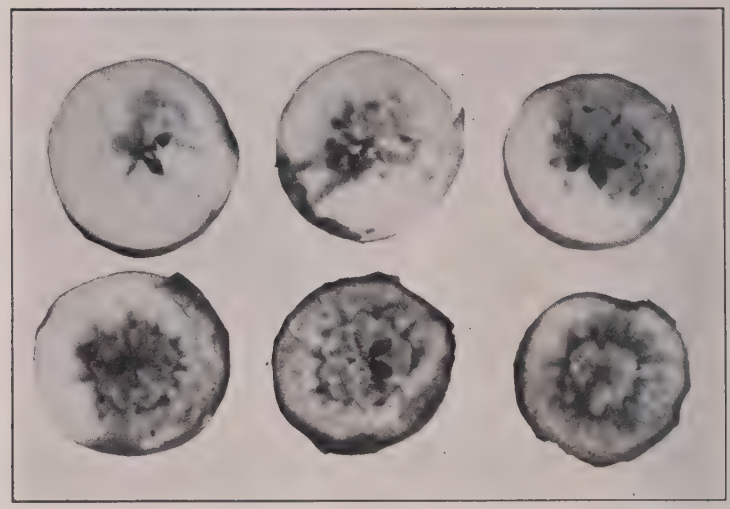

Fig. 5. Six successive stages of mealy breakdown in Grimes, varying from a trace, consisting of a slight browning and mealiness near the carpels, to severe browning and softening of the entire tissue.

tions. It is a common occurrence with summer apples when picking has been delayed too long, or may even occur before picking. Bursting is more common with apples in storage, especially when they have been held too long, or at a too high temperature. This characteristic, however, does not occur uniformly with mealy breakdown.

Fruit may become mealy in storage without showing bursting or either external or internal brown discoloration. Usually, mealiness precedes any brown discoloration, altho it may accompany discoloration. The location of the initial appearance of mealiness and discoloration varies widely with different varieties. With Grimes and Northwestern Greening the initial appearance is within the core or pith region. With Jonathan and some other varieties mealy breakdown begins nearer the skin. With Grimes the discolored portion, which is at first small, increases in size and progresses toward the skin. All stages of mealy breakdown may be found. In Grimes, by the time the browning reaches the skin, a large portion of the apple is brown, soft and mealy. Different stages of mealy breakdown are shown in fig. 5.

Mealy breakdown tissue is slightly lighter brown than that of soggy breakdown. When mealy breakdown follows soggy breakdown in the same apple, it is sometimes possible to distinguish between the two by their color differences.

A large percentage of the fruit reaching a mealy condition becomes affected with rot fungi. When mealiness and skin bursting occur simultaneously, rot fungi soon destroy the tissue. This is probably the reason why much of the fruit reaching a mealy state is observed as "rots" rather than as mealy breakdown, where no effect of rot fungi is present. This may partially explain why the differences between the two types of breakdown, mealy and soggy, have not been more frequently observed.

COMPARISON OF SOME RELATED FUNCTIONAL DISEASES OF APPLES

It will be worth while to consider the various points of similarity, as well as points of dissimilarity, which exist between certain closely related functional diseases of apples.

SOGGY BREAKDOWN AND MEALY BREAKDOWN

Earlier in this paper the writers described soggy breakdown and mealy breakdown of apples.

Soggy breakdown occurs abundantly at the cold storage temperatures, 30° to 32° F. Its initial appearance occurs early in the storage period, usually in December. The disorder begins in the cortical region of the apple and does not usually involve the pith until an advanced stage is reached. When first removed from storage, the affected tissue is of a moist soggy con-

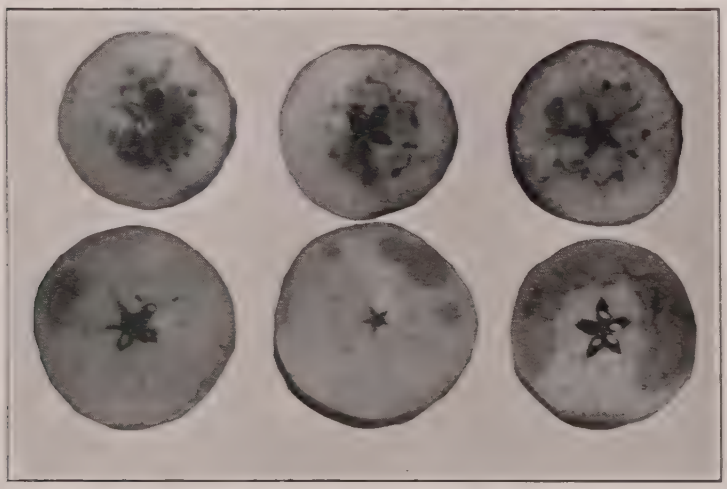

Fig. 4. Soggy breakdown and mealy breakdown on Grimes compared in section. The smaller apples at the top show three stages of mealy breakdown. The large specimens at the bottom show three stages of soggy breakdown. Note that in the latter the core region is not affected, while in mealy breakdown the core region is the first part to become discolored.

Fig. 7. Mealy breakdown following soggy breakdown in Grimes. Original soggy breakdown areas have been outlined. When the apples were removed from the conditions causing soggy breakdown, mealy breakdown followed.

sistency. A characteristic fermented taste is present in the remaining sound tissue, which is an indication of the disease when no discoloration of tissue is apparent. Small specimens appear to be as susceptible as large ones.

Unlike soggy breakdown, mealy breakdown occurs more abundantly at higher storage temperatures, such as prevail in common storage houses. Its initial appearance in storage usually occurs considerably later than does the appearance of soggy breakdown. It may not be evident until late in April or May, provided the storage temperature is not too high. With Grimes, discoloration accompanying the disease begins within the pith region and then spreads outward (tho usually not symmetrically) toward the skin. When removed from storage, the affected tissue, which may involve the entire apple in some cases, is of a dry, mealy consistency. No foreign taste is present, altho a loss in flavor is noticeable in mealy fruit. Large fruit is liable to become mealy earlier than small fruit. Bursting of the skin and the outer cortical region is common when moisture conditions are sufficiently high.

SOGGY BREAKDOWN AND INTERNAL BROWNING

Overholser, et al., (27) and Ballard, Magness and Hawkins (1) have carefully described internal browning of Yellow Newtown apples. While internal browning of Yellow Newtown and

soggy breakdown have certain similarities, the two cannot be considered identical. The two diseases occur abundantly at nearly the same cold storage temperatures (30° to 32° F.); delayed storage increases the amount of injured fruit in either case. Both tend to increase with late picking and appear to vary with the season, altho the latter fact has not been definitely established for soggy breakdown. Both diseases have been pretty well controlled by air movement, such as that secured by the use of electric fans, when the apples were stored without wrappers.

Altho, apparently similar in certain respects, the dissimilarities of the diseases are more striking. The tissues of internal browning that first become brown lie adjacent to and radiate outward from the primary vascular bundles. Internal browning can first be detected in cross sections of the apple in somewhat elongated areas radiating outward from the central portion in the region opposite the basal end of the carpels.

In soggy breakdown the cells near the primary vascular bundles are not at first affected. The disease generally starts outside the primary vascular bundles in the cortex of the apple, leaving the pith or core region entirely free from the trouble. Frequently internal browning appears only around the core, the cortical region remaining sound.

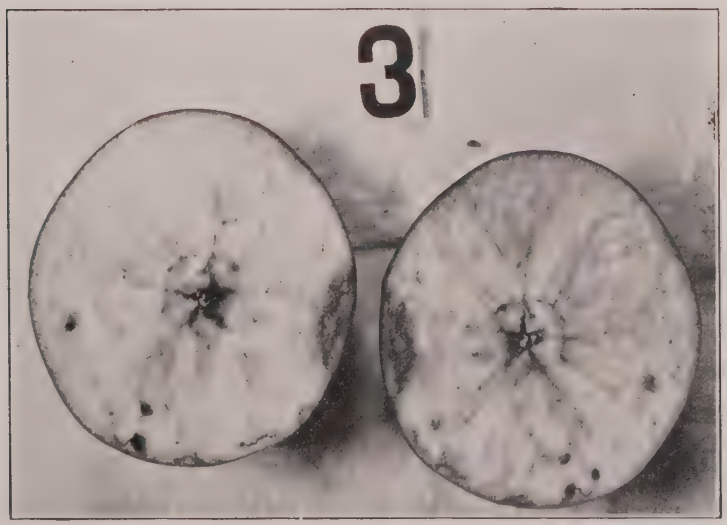

Fig. 8. Internal browning of Yellow Newtown apples. Specimens received from Watsonville, California, thru the courtesy of C. H. Beasley, Supervising Inspector, California Department of Agriculture.

Soggy breakdown is usually insignificant at 34° to 36° F., while internal browning commonly occurs at the latter temperatures. Internal browning is largely confined to the Yellow Newtown variety and to the Pajaro Valley district in California. Altho the disease does occur on other varieties and in other localities, it is much less common. Soggy breakdown, however, occurs commonly on Grimes, Wealthy and probably certain other varieties grown in America. It has occurred on Grimes from Washington state, Michigan and from various sections in Iowa. It has also been reported as internal breakdown on certain varieties of apples in England, Australia, and New Zealand.

SOGGY BREAKDOWN AND BROWN HEART

Kidd and West's (15) description of brown heart has been given earlier in this paper. Brown heart and soggy breakdown of apples are similar in certain characteristics. Both result in death and subsequent browning of internal fleshy tissue, while the peripheral flesh generally remains sound. In late stages, both have a characteristic sponginess caused by the under layers of dead tissues. After removal from storage these brown areas do not become larger but gradually dry up. The adjacent tissues probably absorb water and certain other substances from the dead cells. In this way brown leathery tissue is formed. In either case low temperatures increase the susceptibility of the fruit, while varieties and individual apples differ markedly in their susceptibility.

Altho soggy breakdown and brown heart are apparently similar, they are not identical. They differ considerably in the point of origin. In brown heart, small patches of brown tissue may arise in the cortex or in the pith, or in both. Soggy breakdown arises only in the cortex and not inside of the core line. Apparently, brown heart usually originates within the periphery of the 10 main vascular bundles, while soggy breakdown seldom originates at the main vascular bundles but appears to originate within vascular tissue. Also, soggy breakdown tissues occur in more definite and regular outlines.

Altho apples are more susceptible to brown heart early in storage, it may occur at any stage in the storage life of the fruit. The conditions causing brown heart can produce their effect in a short time. Contrary to this, soggy breakdown occurs only after a definite time interval in storage, at definite stages of maturity, or after certain periods of delayed storage. Soggy breakdown requires considerably more time for development in storage than brown heart. Soggy breakdown is more liable to occur at temperatures below 34° F., making little development at this temperature, while brown heart occurs abundantly at 34° F. and at somewhat higher temperatures. Brown heart is caused by an excessive accumulation of carbon dioxide within

the atmosphere in which apples are stored. A certain percentage of oxygen is essential. Soggy breakdown does not appear to be caused by this condition.

SOGGY BREAKDOWN AND INTERNAL BREAKDOWN

Kidd and West (17) have carefully differentiated between internal breakdown and brown heart. However, they do not clearly indicate that the low temperature type of breakdown, which they call internal breakdown, is different from the internal breakdown due to natural ripening or to senescence in the apple. Kidd, West and Kidd (18) have further stated that, when the average storage temperature maintained is too low, the storage life is prematurely brought to an end by the occurrence of internal breakdown. In such a case, the type of breakdown has not been closely differentiated from the type prevailing at higher temperatures.

To avoid confusion the writers in differentiating between the two types, have named the low temperature breakdown, "soggy breakdown." They consider this identical with the internal breakdown reported by Kidd and West (17) as being caused by low temperature. Soggy breakdown differs considerably from the internal breakdown accompanying senescence or "mealy breakdown." Under the same classification as soggy breakdown is "flesh collapse," which recently has been considered the same as internal breakdown (McClelland and Tiller (26)), and mainly ascribed to a too low storage temperature.

The term "Jonathan breakdown," however, is not included under this category, as it is evidently due to other causes than too low a storage temperature. It is more apt to occur abundantly on fruit stored at higher temperatures than at the cold storage temperatures usually employed. It is more closely allied with mealy breakdown or senescence than with soggy breakdown.

SOGGY BREAKDOWN AND FREEZING INJURY

Freezing injury in apples has often in the past been confused with other functional diseases. Diehl and Wright (10) have shown that cooling apples below their freezing points without the formation of ice in the tissue does not cause visible injury or perceptible softening of the fruit. They found that the average freezing point of all varieties, both eastern and western grown, was 28.5° F., the maximum being 29.4° F., the minimum 27.8° F. They have described in detail both interior and exterior appearances of frozen apples. They stated that a characteristic of frozen fruit, when the whole apple tissue is not involved, is a discoloration of the fibro-vascular system and, in some cases, discoloration of the cambium. In severely frozen fruit a softening and a mushy watery appearance may be noted.

The flesh of the apple sometimes shows a mealy and dry condition.

In describing the visible injury on the surface of apples, they state:

"Surface injury, other than that due to bruising while frozen, consists of discoloration of the surface layers of cells and is usually quite shallow. One of the two usual forms consists of a brown skin discoloration with poorly defined edges resembling a bruise except for a certain water-soaked appearance. This injury is sometimes mistaken for soft-scald but is quite different, because the lesions of soft scald are definite in outline, dull in color and somewhat sunken in a late stage. The other common form of surface injury occurs only on red apples or on the blushed side of the fruit. It is a yellowish-brown discoloration resembling in some cases the work of leaf-miner larvae in leaves. More often it appears as small discolored areas, very irregular in outline, but rather clearly defined."

Excellent colored plates showing various forms of freezing injury on apples may be found in a recent paper by Diehl and Wright (10).

Soggy breakdown differs mainly from freezing injury in that it occurs at temperatures higher than the freezing temperatures of apples. With soggy breakdown, discoloration of the vascular bundles does not usually take place. It also differs from freezing injury in that no definite line of delimitation between sound and affected tissue is generally present in injured fruit. With soggy breakdown frequently no discoloration of the skin takes place—unlike the usual characteristic disfigurement of freezing injury.

Soft-scald and soggy breakdown occur at approximately the same temperatures, altho they cannot be considered identical. Soft-scald is more closely associated with immature fruit and its temperature requirement for development is slightly lower than that for soggy breakdown. Soft-scald first appears on the surface and is confined almost entirely to the outer portions of the apple. It usually does not penetrate lower than 7 mm. beneath the skin. Soft-scald and soggy breakdown usually do not occur simultaneously on the same varieties.

METHODS

The experimental storage work was conducted mainly in the Pomology Section cold storage rooms at Iowa State College. Some fruit was stored each year in a common storage house at the Fred Randau farm, Ames, Iowa. During the past season (1927) the Pomology Section was provided with a new common storage in which additional lots of fruit were placed. Small quantities of fruit were also placed in different commercial cold storage houses.

Fig. 9. Brown heart on English Newton Wonder apples. This photograph was obtained thru the courtesy of Kidd and West of the Low Temperature Research Station, Cambridge, England.

Cold storage temperatures of 30°, 32°, 36° and 40° F. were used the first year of the investigation. For the past two years the same temperatures were used with the exception of 40° F. These temperatures were maintained within ±1° F. the first two seasons and within ±0.5° F. the past season. Standardized thermometers were placed at the lower corners of all the storage rooms just above a false wood floor placed 8 inches above a cement floor. The boxes of fruit were piled at the center of the rooms, leaving working space for a man between the boxes and the walls of the rooms. One 8-inch electric fan was placed at one end of each room. The fans were run thruout the experi-

Fig. 10. English Bramley's Seedling apples with premature internal breakdown, due to low storage temperature. Thru courtesy of Kidd and West.

ment, thus providing a continuous circulation of the storage room atmosphere around the boxes of fruit. In this way the same temperature was secured in all parts of the storage rooms, as shown by the different thermometer readings. Thermometer readings were checked at least twice each day (morning and evening) on week days and once each day on Sundays thruout the course of the investigations. This was done to avoid the possibility of the occurrence of fluctuations in temperatures due to faulty operation of the refrigerating machine. Thermographic records were obtained for each room. The thermographs were checked frequently with standard thermometer readings.

The relative humidity was maintained at a range of 85 to 88 per cent in all except the 30° F. room, which was as low as 80 per cent for certain short intervals. The percentage of moisture was regulated by the use of moist sphagnum moss beneath the false floors. In the two coldest rooms sodium chloride was added to the moss to lower the freezing point of the mixture. The electric fans were of additional service in maintaining the desired humidity. Hygrographic records were obtained thruout all of the experiments and the hygrographs were checked frequently against a standard sling psychrometer.

The variety used in the present report was chiefly Grimes. Wealthy was used in some of the experiments. The best grade of fruit obtainable was used each year, a quality that corresponds to the extra fancy box pack of the Pacific Coast. The time of harvest was generally at the beginning of the commercial picking season, except in the case of fruit picked to determine the effect of maturity at time of harvesting. In 1924 the fruit came from the State Orchard at Council Bluffs, Iowa. In 1925 and 1926 it was obtained chiefly from the Apple Grove Orchards at Mitchellville in central Iowa. To study the effect of locality on soggy breakdown during the past season Grimes apples were obtained from Wenatchee, Washington, Grand Rapids, Michigan, and from different sections in Iowa.* The fruit from distant states was shipped by express to Ames. In 1924 the fruit grown at Council Bluffs was shipped by express. In 1925 and 1926 the fruit from the orchard at Mitchellville was hauled by truck directly to storage.

The Grimes were wrapped in oiled wraps and were packed in standard boxes. The Wealthy were wrapped and packed in

*The writers are greatly indebted to Robert Clark, manager of the Apple Grove Orchards, Mitchellville, Iowa, for his interest and hearty cooperation.

Fruit from Michigan was secured thru the cooperation of V. R. Gardner and H. M. Wells of the Department of Horticulture, East Lansing, Michigan; from Washington, thru the assistance of F. L. Overley and W. A. Luce of the Washington State College at Pullman. E. W. Kreft of the State Orchard, Council Bluffs, Iowa, assisted in obtaining the fruit in 1924.

The writers are also grateful for the interest and cooperation of Fred Randau, Ames, Iowa, who cooperated in the use of his common storage house for three different seasons.

Fig. 11. Mealy breakdown on Iowa Jonathan. Softening and browning of tissue begins near the skin and not near the core, in this variety. This breakdown is due to over-maturity and not to low storage temperature.

standard bushel baskets; as were the Grimes from Michigan. The number of apples per box ranged from 125 to 188 apples. In most cases packs ranging from 125 to 163 were used. The results presented in the tables of this bulletin are expressed in percentage. The percentage in every case is the percentage of apples which became affected with soggy breakdown, based on the original number of apples in each experimental lot.

EFFECT OF STORAGE TEMPERATURE UPON SOGGY BREAKDOWN

Storage temperature is more important in determining the length of storage life of apples than relative humidity and ventilation, altho the latter factors rank next in importance. Since common storage temperatures usually average higher than cold storage temperatures, especially during the early part of the season, the possibility that certain varieties would keep longer at slightly higher temperatures than the usual cold storage temperatures was considered. Experiments were, therefore, carried out to determine the effect of storage temperature on fruit handled under comparable conditions.

In 1924 Grimes for immediate storage and delayed storage were picked on the same day near the end of the commercial picking season. They were packed at the State Orchard, and the boxes for immediate storage were sent by express to Ames, arriving at the laboratory 24 hours after picking. The apples

Fig. 12. "Jonathan breakdown" or mealy breakdown on Jonathan from British Columbia. Specimens secured thru the courtesy of R. C. Palmer, Agricultural Experiment Station, Summerland, British Columbia.

for delayed storage were kept at the orchard until they were ready for shipment to Ames. Different lots of fruit were stored at 30°, 32°, 34°, 36° and 40° F. In addition, other lots were placed in the Randau air-cooled storage. The latter were picked one week earlier, but were otherwise handled in the same manner as the fruit under cold storage.

The following table in addition to showing the outcome of the experiment, shows the time of picking, time of storing and the temperature of storage for the various lots of fruit:

The percentage of soggy breakdown was high at temperatures of 30° and 32° F. It did not occur at 34° F. or at the higher temperatures. This is significant in that the range 30° to 32° F. is close to the usual cold storage recommendation as used in commercial practice.

Delayed storage appears to have increased the amount of the

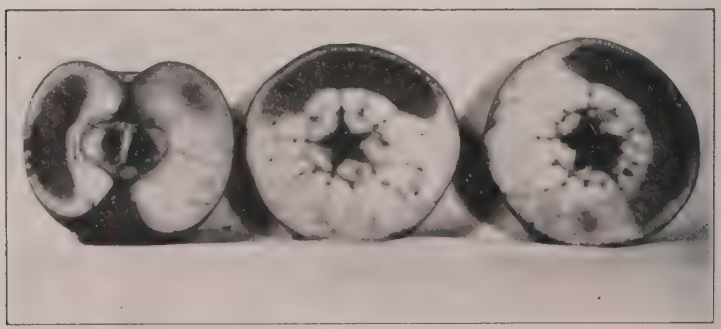

Fig. 13. Soggy breakdown occurring on Grimes from Wenatchee, Washington. Storage temperature 30° F. At 36° F. the disease was not present.

TABLE I. PERCENTAGE OF SOGGY BREAKDOWN ON GRIMES, SEASON 1924-25

Lot No.	Picking date	No. days delayed	Percentage of soggy breakdown					
			Cold storage					Air cooled Storage
			30°	32°	34°	36°	40°	29°—60° F*
1	Oct. 6	1	24.4	11.2	0.0	0.0	0.0	0.0
2	Oct. 6	7	58.3	44.6	0.0	0.0	0.0	0.0
3	Oct. 6	14	54.0	0.0	0.0	0.0	0.0	0.0

*The minimal and maximal temperatures for the various months in air cooled storage were as follows: October, 44°-60° F.; November, 32°-54° F.; December, 32°-39° F.; January, 29°-34° F.

disease at 30° but at 32° a two weeks' delay entirely prevented it. Apparently, a certain amount of delay before storing increases the susceptibility, while a greater amount decreases the susceptibility. The fact that the disease has not appeared at 34°, 36° and 40° or in air-cooled storage is important.

That the effect of low temperatures is not peculiar only to Grimes is indicated in table II. This shows that Wealthy, a fall variety, is subject to the disorder in a similar way.

Altho only very mature fruit that had been delayed was affected, it is significant that no breakdown occurred on apples held in air cooled storage in which considerably higher temperatures prevailed.

TABLE II. COMPARISON OF THE PERCENTAGE OF SOGGY BREAKDOWN OCCURRING ON WEALTHY APPLES UNDER COLD STORAGE AND AIR COOLED STORAGE CONDITIONS; CONDITION IN JANUARY

Lot No.	Date of picking	No. of days delay before storing	Percentage of breakdown	
			Cold storage 32° F.	Air cooled storage 29°—60° F.*
1	August 28	1	0	0
2	August 28	7	0	0
3	August 28	14	0	0
4	September 3	1	0	0
5	September 3	7	0	0
6	September 3	14	0	0
7	September 9	1	0	0
8	September 9	7	0	0
9	September 9	14	3.6	0
10	September 17	1	0	0
11	September 17	7	10.0	0
12	September 17	14	6.6	0

*The minimal and maximal temperatures for the various months in air cooled storage were as follows: October, 44°-60° F.; November, 32°-54° F.; December, 32°-39° F.; January, 29°-34° F.

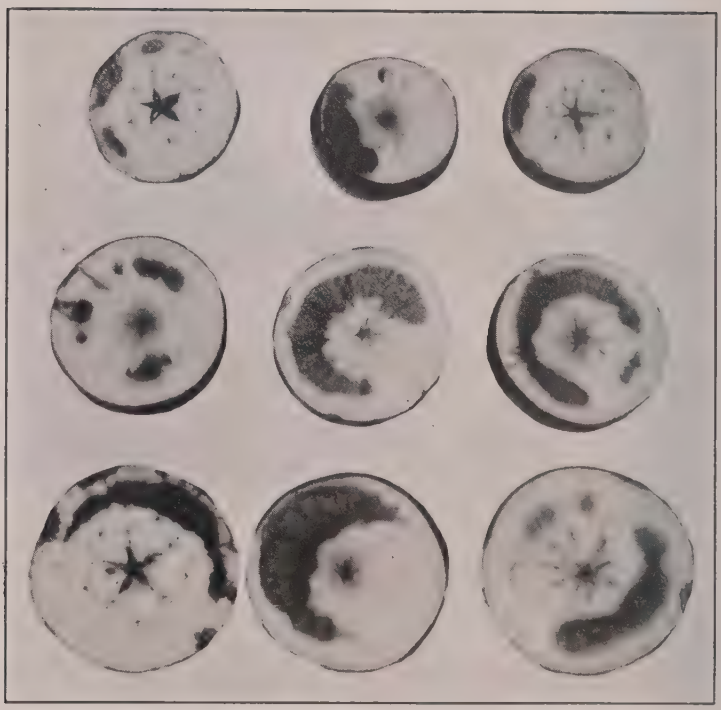

Fig. 14. Grimes from Michigan showing soggy breakdown due to too low a storage temperature. This also shows that size of fruit is not a factor in the development of the disease.

Whether or not results for 1924 were due to unusual seasonal conditions, orchard soil conditions or to some cause other than too low a storage temperature, has been fully determined during the past two seasons. In 1924 the fruit came from western Iowa from old trees growing on Marshall silt loam in the Missouri River loess area. For the past two seasons the main part of the experimental fruit came from Central Iowa from old trees growing in the southern Iowa loess area on Tama silt loam.

Table III gives data on the results showing the effect of low temperature on soggy breakdown over the three seasons 1924, 1925 and 1926. The results were recorded January 20, 1924, February 20, 1925, and February 20, 1926.

The results for 1925 are more significant than those of the previous season. Nearly as much breakdown developed and the effect of delayed storage on the disease is clearly shown by the data. Some breakdown occurred at 34° F., especially with delayed storage fruit. A small amount was also present at

TABLE III. COMPARISON OF THE AMOUNT OF SOGGY BREAKDOWN OCCURRING ON GRIMES UNDER SIMILAR TREATMENTS FOR THREE SEASONS

Year	Picking date	Lot No.	No. days delayed	Percentage of breakdown				
				Cold storage				Air cooled** storage
				Degrees F.				
				30°	32°	34°	36°	
1924	October 6*	1	1	24.4	11.2	0.0	0.0	0.0
1924	October 6*	2	7	58.3	44.6	0.0	0.0	0.0
1924	October 6*	3	14	54.0	0.0	0.0	0.0	0.0
1925	September 16	1	2	2.3	0.0	0.2	0.0	0.0
1925	September 16	2	7	16.5	3.3	0.6	0.0	0.0
1925	September 16	3	14	34.2	8.9	4.5	0.5	0.0
1925	September 16	4	21	56.3	29.4	11.6	2.8	0.0
1926	September 20	1	0	0.9	0.0	0.0	0.0	0.0
1926	September 20	2	7	0.9	2.8	0.0	0.0	0.0
1926	September 20	3	14	4.1	6.8	0.0	0.0	0.0
1926	September 20	4	21	28.8	18.5	7.9	0.0	0.0

*The Grimes' under air cooled storage were picked September 29, 1924.
**In 1926 duplicate lots were placed in two different common storage houses. The results, with respect to the occurrence of soggy breakdown, were the same in each common storage house.

36°, but this amount is hardly significant. No soggy breakdown was present under the common storage treatment.

In 1926 similar results were obtained relative to the prevalence of the disease at the lower temperature and where delayed storage was given, but the disease was somewhat less severe. The trouble did not develop under any of the treatments at 36° F. or in common storage. Under 34° F. and with three weeks' delay, the fruit was affected to the extent of 7.9 percent. With the same amount of delay, the disease was more than twice as severe at 32° F. and over three times as severe at 30° F. The

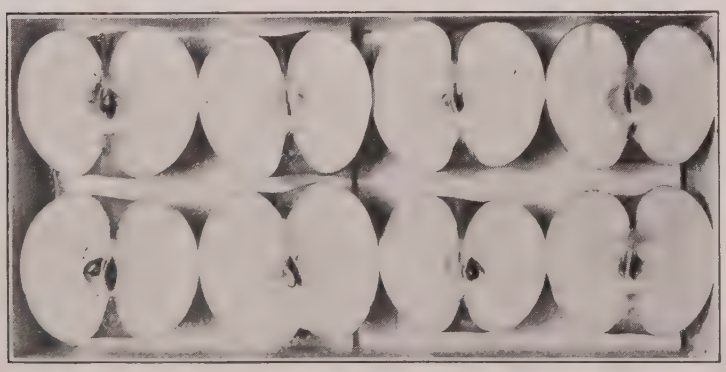

Fig. 15. Sound Grimes removed from air-cooled storage in January. No soggy breakdown was present.

Fig. 16. Grimes taken from air-cooled storage on June 1. Badly scalded areas are beginning to rot on the surface, but there is no soggy breakdown present on this date.

1926 results agree with those for 1925 in that the disease increases proportionately to the lowering of the temperature and to the delay before storing the fruit. The same relation to delayed storage was not so evident in 1924, but it should be remembered that the fruit was picked at the end of the commercial harvest that season, while for 1925 and 1926 the fruit was picked at the beginning of the commercial harvest. The relation of soggy breakdown to delayed storage in 1924 would possibly have been more apparent if the three week delay test had been included that year.

An interpretation of the results for the three years indicates that Grimes is greatly affected by the storage temperature, and that only a slight change in the temperature may influence considerably the duration of the storage life of this variety. It is evident that delayed storage plays an important role in the storage life of Grimes, especially at temperatures lower than 36° F. A temperature of 36° F. proved more suitable for the storage of Grimes than 30°, 32°, or 34° F. However, 34° F. proved considerably better than 30° or 32° F.

Wealthy was not included in the experiments for 1925, but a study was made of the behavior of this variety at different temperatures in 1926. Two types of air cooled storage houses were used, in addition to the four cold storage rooms. Table IV gives the results:

TABLE IV. PERCENTAGE OF SOGGY BREAKDOWN ON WEALTHY, SEASON 1926-1927

(Condition of Fruit January 10)

Lot No.	Picking date	No. days delayed	Percentage of breakdown					
			Cold storage temperature, degrees fahrenheit				Air cooled storage	
			30	32	34	36	College	Randan
1	September 22	2	7.2	2.3	0.0	0.0	0.0	0.0
2	September 22	9	5.2	2.3	0.7	0.0	0.0	0.0

TABLE V. EFFECT OF TIME OF PICKING AND DELAYED STORAGE ON SOGGY BREAKDOWN ON GRIMES

Storage temperature 32° F.
Condition after four days removal from storage

Lot No.	Date of picking	No. days delay before storing	Percentage of soggy breakdown
1	September 22	1	0.0
2	September 22	7	5.8
3	September 22	14	0.5
4	September 29	1	0.0
5	September 29	7	48.4
6	September 29	14	4.8
7	October 6	1	11.2
8	October 6	7	44.6
9	October 6	14	0.0

While the amount of breakdown for Wealthy is lower than that found for Grimes, the relation between low temperature and high breakdown is still evident. The effect of delayed storage appears to be less prominent with Wealthy in this test.

THE RELATION OF MATURITY OF THE FRUIT WHEN PICKED TO SOGGY BREAKDOWN

In the experiments reported in this paper thus far, the Grimes in all cases were picked on the same day at some time during the commercial harvest. A study of the maturity of the fruit by varying the picking date and its relation to soggy breakdown was included in 1924 and in 1926.

In 1924 different lots of fruit were picked at three different times during the commercial season. The first picking was just at the start of the commercial period, the second was at about the middle and the third at the end of the period. The fruit was divided into sub-lots and some was placed in storage the day after it was picked. Other lots were placed in storage after one and two weeks delay from the picking dates. Table V indicates the results of this experiment.

Soggy breakdown did not occur with the immediate storage treatments for the two earliest picking dates but developed to a considerable extent with the latest picked lot. The trouble developed most seriously after one week's delay in each case but was considerably more abundant in the second and third pickings than in the earliest picking. Delaying two weeks at the orchard controlled the disease in the series picked last and reduced it markedly for the other two lots.

The experiment shows that maturity markedly influences the development of the disease, while delayed storage also plays a significant role in its development. These data suggest the probability that there is a certain period after picking after

Fig. 17. Mealy breakdown on Grimes. Note bursting of skin which permits invasion of apple rot fungi.

the apples have been exposed to rather high temperatures, when they are peculiarly susceptible to the development of soggy breakdown. Table II shows that very mature Wealthy are more susceptible to soggy breakdown than the less mature Wealthy.

TABLE VI. EFFECT OF EARLY PICKING ON SOGGY BREAKDOWN ON GRIMES 1926-1927

Storage temperature 30° F.

Condition of fruit February 22

Lot No.	Picking date	No. days delayed	Percentage of soggy breakdown
1	September 6	1	0.0
2	September 11	2	0.0
3	September 15	2	1.9
4	September 20	0	1.0

The effect of under-maturity on the development of soggy breakdown was given especial attention in 1926. That high acidity and a slow rate of loss of acid in apples are conditions favoring the development of internal breakdown has been suggested in the work of Haynes (14). In 1926 the writers began the picking of Grimes as early as September 6, at which time the fruit was extremely green, hard and showed all indications of immaturity. This fruit was stored one day after picking. Other pickings were made on each succeeding fourth day until the beginning of the commercial harvest, September 20. The condition of the fruit late in February, with respect to the amount of soggy breakdown, is given in table VI.

Lot No. 1 was stored at 34° for the first 6 days, then 32° for 5 days and after that at 30°. Lot No. 2 was held at 32° for 5 days, then 30° thereafter.

The results are negative, since no significant amount of breakdown developed. It is evident that extreme immaturity does not necessarily increase the amount of soggy breakdown, provided the fruit is stored soon after picking. The effect of delayed storage on very immature fruit will be a point for future investigation.

INFLUENCE OF SEASON UPON SOGGY BREAKDOWN OF APPLES

Whether or not apples are more susceptible to breakdown one year than another has long been disputed. Growers and apple

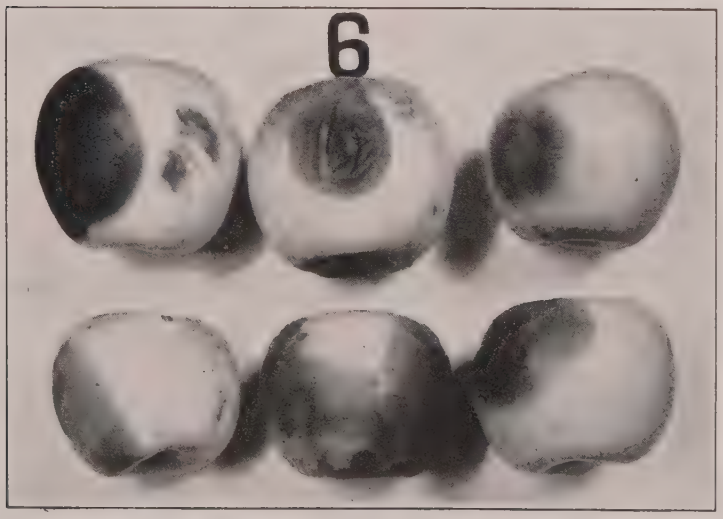

Fig. 18. Mealy breakdown not accompanied with bursting. External browning present as well as internal.

TABLE VII. MEAN TEMPERATURES AND MEAN DAILY FLUCTUATIONS OF TEMPERATURES DURING GROWING SEASONS, AND DATA RELATIVE TO THE OCCURRENCE OF SOGGY BREAKDOWN

Year	Station	May	June	July	August	September	October	Season mean	Date of picking	Max. breakdown at 30°*
1924	Omaha	55.7±10.3	69.0±10.07	73.2± 9.8	76.0±10.0	62.2± 9.8	61.4±11.4	66.3±10.2	Oct. 6	58.3
1925	Des Moines	59.4±11.9	72.0±10.4	76.3±11.3	73.8±10.9	70.4± 9.4	41.6± 8.1	65.6±10.3	Sept. 16	56.3
1926	Des Moines	65.4±12.2	67.9±10.7	76.2± 9.7	75.8±10.0	64.1± 7.9	53.0± 9.3	67.1±10.0	Sept. 20	28.8

*The maximum amount of breakdown occurred on fruit delayed for one week in 1924 and upon fruit delayed three weeks in 1925 and 1926.

TABLE VIII. TOTAL PRECIPITATION FOR GROWING SEASON, AND DATA RELATIVE TO THE OCCURRENCE OF SOGGY BREAKDOWN

Precipitation in inches

Year	Station	May	June	July	August	September	October	Total for growing season	Date of picking fruit	Max'mum breakdown at 30°F.
1924	Omaha	2.01	9.08	2.79	1.67	4.56	0.51	20.62	Oct. 6	58.3
1925	Des Moines	0.77	6.44	2.21	4.79	3.75	3.22	21.18	Sept. 16	56.3
1926	Des Moines	2.11	6.11	3.69	2.95	10.25*	0.73	25.84	Sept. 20	28.8

*Of the total amount of rainfall in September, 1926, 8.05 inches fell before September 20, the day the fruit was picked.

dealers commonly consider that fruit grown during seasons of excessive moisture is lower in keeping quality than that grown in seasons of normal rainfall. Orchard temperatures and the amount of soil moisture undoubtedly have some influence from year to year, since these factors are known to alter the growth conditions and hence the size, color, hardness and rate of ripening of the fruit.

The influence of seasonal conditions upon the trouble in this investigation deserves some consideration. Table VII made up of data taken from the United States Department of Agriculture Weather Bureau Climatological Data records gives a comparison of the mean temperatures and the mean daily fluctuations of temperatures during the growing season of the apple for the three seasons in which the study of soggy breakdown has been under way.

The maximum amount of soggy breakdown occurring at 30° F. is shown for each season. Table III also shows the relative amount of the disease for the three seasons.

The margin of difference between the mean temperature for the three growing seasons is not marked. The mean daily fluctuation of temperatures for the same periods is insignificant. Altho the monthly mean temperature was higher for September and considerably lower for October in 1925 than in 1924, no great difference in the amount of breakdown is shown between the two seasons. The comparatively low amount of breakdown in 1926 can hardly be attributed to the slightly higher mean seasonal temperature or to unusual temperature conditions during any part of the growing season.

The importance of rainfall and its influence on the growth and maturity of apples has been considered.

Table VIII gives data showing the total precipitation for each month and for the apple growing season for the three years under consideration. In 1926 unprecedented rains occurred in September. Of the 10.25 inches of rainfall during September in 1926, 8.05 inches fell before the apples were picked (September 20).

The effect of the excessive moisture just before the harvest in 1926 may have influenced the prevalence of soggy breakdown that year. In an earlier paper the writers (31) called attention to a similar occurrence when excessive rain prevailed just before picking. Data were presented which indicated that excessive precipitation just before picking accelerated the rate of growth in Grimes. Other effects noted, and attributed to excessive moisture, were an increase in starch content with decreases in total sugars and acidity. However, no corresponding decreases in the amount of breakdown attributable to excessive

Fig. 19. Mealy breakdown on Grimes in section. The specimens are sections of some of those shown in fig. 17. The amount of browning is less intense than in soggy breakdown and grades off gradually into the white, uncolored portions. Flesh is very mealy.

moisture could then be observed. The keeping quality of the fruit picked a few days after the excessive rain proved to be as good as that picked before the rain. This is similar to the result obtained in 1926, when a lower amount of breakdown occurred with excessive moisture. From the results in table VIII, fruit grown during seasons with excessive moisture apparently is not more apt to break down than fruit grown in normal seasons. On the contrary, it appears that the storage life of such fruit is fully as long as that grown in seasons with an amount of moisture nearer the normal.

The effect of excessive moisture thruout the entire growing season may be considered. The total amount of rainfall for the growing season in 1926 was higher than that for the other two seasons (table VIII). Other weather bureau data for the entire year show the total amount of rainfall for 1924, 1925 and 1926 to be 26.80, 26.42 and 32.85 inches, respectively, at the stations noted. The mean precipitation over a period of years is 32.06 inches at Des Moines and 26.83 inches at Omaha. From this it will be noted that the years 1924 and 1925 were unusually deficient in moisture.

The fact that a comparatively lower amount of breakdown occurred in 1926 as compared to 1924 and 1925, suggests that the disease may be more prevalent during years when low

moisture conditions prevail. However, the writers are aware that the disease has been common year in and year out in cold storage fruit, during years when the precipitation has been about normal and somewhat above normal.

THE INFLUENCE OF LOCALITY UPON SOGGY BREAKDOWN OF GRIMES

In order to determine whether the injury noted on Grimes was solely confined to apples grown under conditions of Iowa, Grimes were obtained from the Wenatchee district of Washington and from the Graham Experimental Station near Grand Rapids, Michigan. In addition to these, Grimes were secured at two points in Iowa; Mitchellville, which is in the vicinity of Des Moines, and Ames, which is approximately 35 miles farther north. Climatic and soil conditions vary considerably between the two Iowa points, and the Grimes grown at Ames mature somewhat later than those grown at Mitchellville.

The Grimes from the three states were all picked during the commercial harvest. The picking dates for the Washington, Mitchellville, and Michigan fruit were September 15, September 20 and October 12, respectively. The Grimes grown at Ames were picked September 25.

The Grimes from Wenatchee were already of eating maturity and quality when they reached Ames. They were shipped by express and were received at Ames six days after picking. They were considerably softer, sweeter to the taste and had more color than the Iowa grown fruit, which had been picked and held for seven days at the orchard. The pressure test measurements for the Washington Grimes, as determined by the instrument devised by Magness and Taylor (20), were considerably lower than those for Grimes grown at Mitchellville and given

Fig. 20. Mealy breakdown of Northwestern Greening. Note bursting of skin and browning near the core region. Storage temperature 40° F.

similar treatment. The pressure test readings for comparable lots from Washington, Iowa and Michigan when placed in storage were 12.9, 16.4 and 18.7 pounds, respectively. The Grimes from Iowa (Mitchellville) were apparently intermediate in the degree of maturity attained, according to their hardness. The Washington Grimes had already reached an edible stage, while those from Iowa and Michigan were still too immature to eat upon their arrival at the storage laboratory. The Michigan grown fruit showed less color and less maturity than those from Ames. Three days were consumed in its shipment from Grand Rapids to Ames.

All of these Grimes were placed under the same storage conditions at Ames. In each case, some fruit was stored immediately after picking at Wenatchee and at Grand Rapids in commercial cold storage houses. These lots were later sent by express to Ames and there examined at the end of the storage season. The Grimes stored at Wenatchee were held at 32° to 34° F.; and those stored at Grand Rapids were held at 33° to 34° F.* The results of the investigations are given in table IX.

The data are not entirely complete for the various temperatures for the Washington and Michigan Grimes, but sufficient evidence shows that soggy breakdown may become very severe

TABLE IX. PERCENTAGE OF LOW TEMPERATURE BREAKDOWN ON GRIMES AND COMPARISON OF GRIMES FROM DIFFERENT LOCALITIES, SEASON 1926-27.

Lot No.	Locality where grown	Place and type of storage	Picking date	No. days delaye	Percentage of breakdown			
					30°F.	32°F.	34°F.	36°F.
1	Mitchellville, Ia.	Ames, experimental	Sept. 20	0	0.9	0.0	0.0	0.0
2	Mitchellville, Ia.	Ames, experimental	Sept. 20	7	0.9	2.8	0.0	0.0
3	Mitchellville, Ia.	Ames, experimental	Sept. 20	14	4.1	6.8	0.0	0.0
4	Mitchellville, Ia.	Ames, experimental	Sept. 20	21	28.8	18.5	7.9	0.0
5	Ames, Ia.	Ames, experimental	Sept. 25	2	23.1	15.6	4.6	0.0
6	Ames, Ia.	Ames, experimental	Sept. 25	11	58.2	37.7	---	0.6
7	Wenatchee, Wash.	Wenatchee, Wash., commercial	Sept. 15	1	----	1.1	---	---
8	Wenatchee, Wash.	Ames, experimental	Sept. 15	7	79.3	12.0	8.8	0.0
9	Wenatchee, Wash.	Ames, experimental	Sept. 15	14	43.0	25.0	---	---
10	Wenatchee, Wash.	Ames, experimental	Sept. 15	21	12.4	8.3	---	---
11	Grand Rp's, Mich.	Grand Rapids, commercial	Oct. 12	1	----	---	0.0*	---
12	Grand Rp's, Mich.	Ames, experimental	Oct. 12	3	0.0	0.0	---	---
13	Grand Rp's, Mich.	Ames, experimental	Oct. 12	7	0.0	4.5	---	---
14	Grand Rp's, Mich.	Ames, experimental	Oct. 12	14	43.4	40.0	---	---
15	Grand Rp's, Mich.	Ames, experimental	Oct. 12	21	56.2	46.8	---	---

The Grimes from Iowa were examined February 17.
The Grimes from Wenatchee were examined January 20.
*The Grimes from Michigan were examined February 23. Lot No. 11 was stored at 33°-34° F.

Fig. 21. Mealy breakdown on Golden Delicious apples. Note severe bursting without much discoloration.

on Michigan and Washington grown Grimes, as well as on those grown in Iowa. The Grimes from Washington developed more of the disease than those from either of the other sections, probably because the fruit was more mature when placed in storage.

A preliminary examination on December 16 showed that the Washington fruit had already developed the disease seriously, while the Grimes from Iowa and from Michigan had not yet shown any development. The trouble developed latest on the Michigan fruit. It appears that the Iowa fruit was intermediate in its susceptibility to the disease, just as it was intermediate in maturity. More breakdown was present on the Michigan fruit than on the Iowa fruit grown at Mitchellville but not any more than on the fruit grown at Ames.

The importance of storage temperature is shown in the fruit from every section. With only one exception, wherever comparison is possible, the disease was most abundant at 30° F. and next most abundant at 32° F. The one exception occurred with Mitchellville fruit delayed for two weeks, in the lots stored at 30° and 32° F., but the margin of difference was small. The disease was much less severe at 34° than at the two lower temperatures and at this temperature it was usually on the delayed stored fruit. The fact that the disease was well controlled at 36° F. is significant, since the storage life of the fruit was materially increased at this temperature.

*These temperatures were verified by W. A. Luce at Wenatchee and by the Kent Cold Storage Company at Grand Rapids.

The importance of delayed storage is also evident. With the fruit from Iowa and Michigan, which was less mature than the Washington fruit, there was a tendency for the disease to increase proportionately with the amount of delay. With the Washington fruit, which had apparently reached a higher degree of maturity, the disease was highest under the one week delay treatment. After that the amount of the disease decreased as the delayed storage period was lengthened.

These results again suggest the probability that fruit reaches a susceptible period caused by rather short exposures to ordinary temperatures previous to storing at the usual cold storage temperatures. Probably, if the treatment at ordinary temperatures is prolonged sufficiently, the fruit no longer becomes susceptible, or at least decreases in susceptibility to soggy breakdown.

THE EFFECT OF AERATION OF FRUIT IN OPEN AND CLOSED CONTAINERS DURING THE STORAGE PERIOD ON SOGGY BREAKDOWN

The effect of aeration or air movement such as was obtained by the continuous use of electric fans was observed thruout two storage seasons. Fruit, placed in open wire baskets without wrapping, was so arranged as to be continuously in the direct path of the breeze created by the electric fan. The closed containers were the usual standard apple boxes and were stored in the same room with the open containers but not in the direct breeze of the fan. The apples in the closed containers were wrapped in commercial oiled wraps.

In 1924 the apples were picked at three stages of maturity and stored at weekly intervals after picking at 32° F. In 1925 one picking was made during the commercial season and the fruit was stored two days later at temperatures of 30°, 32°, 34° and 36°. One box of fruit was used as the unit for each test.

TABLE X. EFFECT OF AERATION DURING THE COLD STORAGE PERIOD ON SOGGY BREAKDOWN ON GRIMES

Season 1924-1925

Condition after four days removal from storage

Lot No.	Picking date	No. days delay before storing	Percentage of soggy breakdown at 32° F.	
			Without aeration, fruit wrapped; in standard boxes	With aeration, fruit unwraped; in open wire baskets
1	September 22	1	0.0	0.0
2	September 22	7	5.8	0.0
3	September 22	14	0.5	0.0
4	September 29	1	0.0	0.0
5	September 29	7	48.5	0.0
6	September 29	14	4.8	0.0
7	October 6	1	11.2	0.0
8	October 6	7	44.6	0.0
9	October 6	14	0.0	0.0

Fig. 22. Severe bursting and mealy breakdown on Grimes. This occurred on fruit placed under a bell jar at ordinary temperatures and at a high humidity.

The results for 1924, tabulated in table X, are very striking as no breakdown occurred in the open containers. This may be due to the fact that the apples in the open wire baskets lost more moisture than those in the closed containers. A visible amount of shriveling was observed on the fruit in the open containers. The hypothesis, that loss of moisture content in apples is directly related to the type of breakdown occurring, is in harmony with some of the results reported by McClelland and Tiller (26). However, the amount of moisture loss which would be sufficient to control the disorder apparently would also be sufficient to produce visible shriveling. This is objectionable since a reduction of only 5 percent in the relative humidity during the storage season may produce visible shriveling. This method of attack does not appear entirely practical as a control method. However, the practice of storing apples in a humidity higher than is necessary to prevent shriveling may be objectionable. The beneficial results of air movement in the removing of certain toxic substances accumulated within the apple tissue may be another explanation of the results obtained. Aerating during the storage period was tried again in 1925.

The data on aeration during the season of 1925 are tabulated in table XI. Only small amounts of soggy breakdown were

TABLE XI. EFFECT OF AIR MOVEMENT ON DEVELOPMENT OF SOGGY BREAKDOWN ON GRIMES STORED IN OPEN AND CLOSED CONTAINERS, SEASON 1925-1926

Lot No.	Date of picking	No. days delay	Storage Temp. (degrees)	Percentage of soggy breakdown	
				With air movement, fruit wrapped; in standard boxes	With air movement, fruit unwrapped; in open wire baskets
1	September 16	2	30	2.3	0.3
2	September 16	2	32	0.3	1.8
3	September 16	2	34	0.3	0.2
4	September 16	2	36	0.0	0.0

present, even at the lower temperatures. This can be explained on the basis that the fruit used was not subject to soggy breakdown because it was not delayed at the orchard. The data in table III for 1925 bear this out; as little or no breakdown occurred with the fruit stored two days after picking. The experiment would have been more significant if delayed storage fruit had been included. These data again show that fruit may not necessarily be subject to the trouble even at low temperatures.

THE EFFECT OF AERATION DURING DELAYED STORAGE ON SOGGY BREAKDOWN

The beneficial effects of ventilating apples during delayed storage in the control of apple scald has been shown by Brooks, Cooley and Fisher (3), (5). Whether or not similar treatment would prove advantageous in the control of soggy breakdown on apples was noted in an experiment in 1924. Different lots of fruit placed in open slatted crates were freely exposed to the air for weekly intervals from the time of picking to the date of packing and storing. Other comparable lots were wrapped and packed in standard boxes immediately after picking and then placed with other commercial boxed fruit at 32° F. This

TABLE XII. EFFECT OF AERATION DURING THE DELAYED STORAGE PERIOD ON SOGGY BREAKDOWN ON GRIMES

Condition after four days removal from storage

Lot No.	Picking date	No. days delay before storing	Percentage of soggy breakdown	
			Without aeration, fruit wrapped; in standard boxes	With aeration, fruit unwraped; in open slatted crates
1	September 22	7	5.8	26.4
2	September 22	14	0.5	0.0
3	September 29	7	48.4	60.2
4	September 29	14	4.8	12.6
5	October 6	7	44.6	42.3
6	October 6	14	0.0	0.0

treatment was carried out for early, intermediate and for late picked fruit. The results of this study are shown in table XII.

Contrary to the idea that ventilating the fruit would inhibit the development of soggy breakdown, the ventilated fruit showed in the main more breakdown than that which was packed in the usual manner. Whether or not ventilation was the chief contributing factor for more development of the trouble was not fully determined. However, the results with the ventilated fruit are in harmony with those for the unventilated, in that the lots which received the same amount of delay after each picking show correspondingly high or low breakdown. These data again suggest that apples may reach a certain period of susceptibility to soggy breakdown after exposure to ordinary temperatures.

It is apparent that aeration in open slatted crates during the delayed storage period does not offer a direct method for controlling soggy breakdown of apples.

COMPARISON OF THE AMOUNT OF SOGGY BREAKDOWN DEVELOPING ON GRIMES UNDER COMMERCIAL AND EXPERIMENTAL STORAGE

Practically all of the experimental work of the Pomology Section has been carried on in the cold storage laboratory of the Plant Laboratory Building, Iowa State College. As the rooms used to store the fruit are small* in comparison with those used for commercial storages, better temperature control is probably possible than is secured in the larger storages. Whether such storage disorders as soggy breakdown and soft-scald of apples are more common in experimental storages than in commercial storages, is a question occasionally asked. An experiment, which showed that soggy breakdown occurred under both types of storage, was carried out during the 1926 season. Comparable lots of fruit were stored in the Central

TABLE XIII. COMPARISON OF AMOUNT OF SOGGY BREAKDOWN ON GRIMES UNDER COMMERCIAL AND EXPERIMENTAL STORAGE, SEASON 1926-1927

Lot No.	Picking date	No. days delay	Percentage of soggy breakdown	
			Commercial storage 32°—33°F.	Experimental storage 32°
1	September 20	0	0.0	0.0
2	September 20	7	0.0	2.8
3	September 20	14	0.0	6.8
4	September 20	21	23.0	18.5

*The present capacity of the storage rooms for experimental purposes varies from 25 to 75 boxes of fruit.

Service Cold Storage at Des Moines and in the experimental storage at Ames.

Table XIII shows that soggy breakdown developed severely under commercial storage as well as under experimental storage. Lot No. 4 under commercial storage showed 14.0 percent soggy breakdown on January 29, while lots 1, 2, 3 and 4 under experimental storage showed no significant amount of breakdown on this date. The percentage of breakdown shown in table XIII for commercial storage is for February 9, and for experimental storage fruit for February 18. The disease appeared first upon the commercial storage fruit, and the development was most severe under this treatment.

The experiment shows that soggy breakdown is as liable to occur under commercial storage as under experimental storage.

EFFECT OF TEMPORARILY STORING AT A SLIGHTLY HIGHER TEMPERATURE BEFORE PLACING AT USUAL COLD STORAGE TEMPERATURES ON THE DEVELOPMENT OF SOGGY BREAKDOWN

Due to the possibility that certain objections might arise to the storing of Grimes continuously at 36° F., a study was included to show the effect of storing Grimes temporarily at 36° F. and then later reducing the temperature to 30° and 32° F. Four boxes each of Grimes were stored at 36° F. for periods of four, six and eight weeks, respectively. After these periods in storage at 36° F., two boxes of each lot were placed at 30° and the other two boxes at 32° F., for the remainder of the season. The percentage of soggy breakdown occurring in each lot with the arrangement of the different lots is shown in table XIV. The experiment was carried out the same way for two different seasons.

TABLE XIV. TEMPORARILY STORING AT A SLIGHTLY HIGHER TEMPERATURE BEFORE PLACING AT USUAL COLD STORAGE TEMPERATURES AND ITS EFFECT ON THE DEVELOPMENT OF SOGGY BREAKDOWN

Year	Fruit stored temporarily at 36° then at 30° and 32°						Checks at 30°, 32°, and 36°		
	Picking date	No. days delay	Duration of temporary storage at 36° F.	Date of exam.	Percentage of breakdown with temporary storage 36°		Percentage of breakdown with continuous storage		
					30°	32°	30°	32°	36°
1925	September 16	2	4 weeks	Feb. 19	11.02	3.74	2.3	0.0	0.0
1925	September 16	2	6 weeks	Feb. 19	2.49	1.17	---	---	---
1925	September 16	2	8 weeks	Feb. 19	0.27	0.0	---	---	---
1926	September 20	0	4 weeks	Feb. 22	0.5	0.0	0.9	0.0	0.0
1926	September 20	0	6 weeks	Feb. 22	0.0	0.0	---	---	---
1926	September 20	0	8 weeks	Feb. 22	0.0	0.0	---	---	---

These data do not show the same result for both seasons. The data for 1925 suggest that the apple may be highly susceptible to soggy breakdown during certain periods, and that the disease occurs when the storage temperature is rapidly reduced.

In 1925 this condition was apparently present after the fruit had been stored at 36° F. for four weeks. After eight weeks storage at 36° F. this condition had disappeared, as the fruit never developed the trouble to any appreciable extent. Storing Grimes for six weeks at 36°, before lowering the temperature to 30° and 32° F., reduced the amount of the disease from 11 to 2.5 percent at 30° F. and from 3.7 to 1.2 percent at 32° F.

The fruit held at 30° and at 32° F. continuously from the time of picking developed only a small amount of the disease, while that which was delayed one week at orchard temperatures and then stored at 30° F. developed a considerable amount of the injury. Further, the proportion of breakdown increased with the amount of delay given at orchard temperatures, when the cold storage temperatures were 30° and 32° F. However, when the storage temperature was 36° F., thruout the storage period, no appreciable amount of soggy breakdown developed on either the fruit which was stored immediately or on that delayed for various periods at orchard temperatures. Evidently at certain periods in the life of the apple a sudden lowering of temperature is detrimental, due to the occurrence of soggy breakdown.

The disease made practically no development under the conditions of the experiment for 1926, probably due to the fruit being less susceptible to the injury that season. The data given in table III indicate this probability, since delayed storage fruit has been found to be more susceptible.

RATE OF SOFTENING OF GRIMES DURING DELAYED STORAGE TREATMENT AND DURING THE STORAGE SEASON AT VARIOUS TEMPERATURES

Pressure test readings of the fruit were obtained using the Magness and Taylor apparatus (20). In each test 12 apples were used, and three tests were made on pared portions on each apple, giving a total of 36 readings. The readings were averaged to represent the mean hardness in pounds pressure of the fruit.

The pressure tests on Grimes were obtained at the time of picking, when the different lots were placed in storage and upon their removal from storage. The actual tests obtained showing the relative hardnesses of the various lots are indicated in table XV.

The greatest amount of softening occurred while the fruit was delayed at ordinary temperatures. There is a progressive rate of softening of approximately 2 to 3 pounds per week during this delay.

TABLE XV. PRESSURE TEST OF LOTS OF GRIMES UNDER TEMPERATURE EXPERIMENT WHEN STORED, AND AT END OF STORAGE, SEASON 1926-1927

Hardness in pounds pressure

Date picked	No. days delayed	Test when stored	Test February 20, 1927, after storing at various temperatures				
			30°	32°	34°	36°	Air cooled storage
Sept. 20	0	18.1	11.3	10.3	10.1	10.1	8.4
Sept. 20	7	16.4	10.5	11.1	10.5	10.7	8.4
Sept. 20	14	13.5	10.0	10.3	10.1	10.1	8.9
Sept. 20	21	10.9	9.4	10.1	10.1	8.9	8.4
Average			10.3	10.45	10.2	9.95	8.52

The results on softening during storage are not always consistent and indicate that the method used is not accurate enough to measure the differences in the rate of softening in apples at different temperatures, even when the temperature range varies 2° F. However, there is an indication that the ripening processes, as measured by the softening rate, are somewhat more rapid at 36° F. than at 30° or 32°. The low figures for the fruit under common storage were probably closely approached early in the storage season when the temperature was highest.

Nearly all the fruit reached the same degree of hardness in common storage, regardless of marked differences in the different lots when they were placed into storage. The data show that the rate of metabolic changes varies in apples stored under slightly different temperatures, as measured by degree of hardness. They further emphasize the rapid softening which occurs in fruit at ordinary temperatures in the orchard.

THE CONDITION OF THE FRUIT AFTER STORING AT VARIOUS TEMPERATURES

The writers have found that the eating quality of Grimes, and condition generally, is decidedly improved when the fruit is stored at 36° F. rather than 30° and 32°. The color of Grimes apples at harvest time is not uniform, being mainly a green rather than a yellow. A few specimens reach a definite yellow color on the tree at harvest time and appear to keep as well, or better, than the green fruit. When Grimes are stored at 32° or 30° F. the same day they are picked, or even a few days later, the characteristic rich, golden yellow of well ripened Grimes rarely develops. Even as late in storage as February, such fruit appears immature in color, and distinctly lacks the richness and aroma of well matured fruit.

In contrast to this, when Grimes are stored at 36° F. immediately after picking, practically all of the fruit gradually becomes a deep yellow, and at the end of the storage period in December or in January it is in prime condition. Such fruit is more attractive and possesses the high eating quality charac-

teristic of the variety. Even tho storage is delayed, the fruit is of superior color and quality when compared with fruit stored at lower temperatures. Delayed storage fruit has proved very susceptible to soggy breakdown when stored at the lower temperatures. Fruit which has been stored at 34° F. is intermediate between fruit held at 32° and 36° F. in eating quality and color and is considerably better than that stored at 30° F.*

When samples of the fruit were removed from cold storage on March 1, 1927, the color and eating quality of the 16 different lots of Grimes were noted carefully. In general, there were approximately four shades of yellow, or one shade for each lot as determined by the time of storage. For example, the immediate storage fruit was much greener than that which was delayed for two weeks or for three weeks. Differences in the time that the fruit went into storage influenced the color development of the fruit more than the differences in the storage temperatures.

In general, apples which could be rated intermediate in color, almost always were in prime condition, while those which could be rated as a deep or amber yellow were almost always over mature and lower in eating quality. Apples described as green or

TABLE XVI. CONDITION OF GRIMES' ON MARCH 1 AFTER STORING AT VARIOUS TEMPERATURES

Treatment	1		2		3	
	Flavor	Color	Flavor	Color	Flavor	Color
	Immature; Insipid	Green or Yellowish green	Excellent; Characteristic	Lemon or medium yellow	Past prime; Overmature	Amber or dark yellow
Immediate storage at 30°	X	X				
Immediate storage at 32°	X	X				
Immediate storage at 34°	X	X				
Immediate storage at 36°			X	X		
Delayed 1 week, stored at 30°	X			X		
Delayed 1 week, stored at 32°	X			X		
Delayed 1 week, stored at 34°			X	X		
Delayed 1 week, stored at 36°			X	X		
Delayed 2 weeks, stored at 30°	X			X		
Delayed 2 weeks, stored at 32°			X	X		
Delayed 2 weeks, stored at 34°			X	X		
Delayed 2 weeks, stored at 36°			X	X		
Delayed 3 weeks, stored at 30°					X	X
Delayed 3 weeks, stored at 32°					X	X
Delayed 3 weeks, stored at 34°					X	X
Delayed 3 weeks, stored at 36°					X	X

*The writers have not relied entirely upon their own judgment in the comparisons made on the quality and attractiveness noted between Grimes stored at 36° F. and Grimes held at 30° to 32° F. Various members of the staff of the Horticulture Department of Iowa State College and others have without exception favored the fruit stored at the higher temperature, on the basis of higher eating quality and more attractive color.

yellowish green were still too immature and had not acquired the full rich Grimes flavor. Such fruit, it has been observed, never develops the desirable characteristic Grimes flavor.

The apples stored at 36° F were nearly all a uniform yellow in color and were better in eating quality and general condition. The fruit stored at 34° approached this condition rather closely, while that taken from 32° and 30° F. storage were more variable, having more green fruit. Lack of uniformity in color is more pronounced at 30° than at 32° F. Likewise there is more green fruit and lack in color uniformity at 32° than at 34°, and more at 34° than at 36° F.

The condition of the fruit in regard to color and eating quality is summarized in table XVI.

Growers and dealers frequently have reported inability to sell Grimes readily because of lack of color and attractiveness when placed on the market after storage. The writers believe this difficulty can be overcome by storing Grimes at 36° F. thruout the storage period.

Over a period of years the writers have noted that, when well graded high quality fruit has been stored, the increase in loss due to rot fungi at 36° F. is very slight. Increased rotting, if any, in fruit stored at 36° F. is of minor importance when compared with the benefit derived thru the prevention of soggy breakdown.

Whether the increased tendency to scald at the slightly higher temperatures is sufficient to discount the benefit derived by the elimination of soggy breakdown is another question. Brooks, Cooley and Fisher (5) have reported experiments on Grimes which showed that low temperature delayed scald rather than prevented it. They found that the disease was as serious at 32° F. at the end of 16 weeks' storage as it was at 41° F. at the end of 12 weeks. They further state:

"The scald control obtained with oiled wrappers has been largely in the nature of removing the tendency to scald rather than merely delaying the development of the disease."

In the investigations under consideration in which oiled wrappers were used, the writers found thruout that apple scald was either reduced to a minimum or was entirely controlled. Scald, in some instances was found more prevalent after removal from storage on fruit which had been held at the lower temperatures. Grimes which had been held at 36° F. were a deeper yellow color, more mature and less liable to scald than fruit stored at lower temperatures. The scald appearing on the fruit held at the lower temperature was of a more serious nature than that developing on the more mature fruit held at 36° F. However, the amount of scald present on the fruit in oiled wraps was markedly less than on fruit wrapped in ordinary paper. In

nearly all cases scald has been so well controlled by the use of oiled paper that any increase due to a few degrees rise in temperature has not been sufficient to off-set the advantages of controlling soggy breakdown. If the fruit is wrapped in oiled paper, apple scald need not be considered as discounting the beneficial results to be obtained by preventing the development of soggy breakdown when the fruit is stored at 36° F. as compared to 30° and 32° F. The kind of oiled paper is important. Good results on scald control have been secured with wrappers containing 16 to 20 percent of their weight in oil, and still better results have been obtained when the amount of oil was from 20 to 22 percent.

The behavior of Grimes after removal from storage at different temperatures has been under observation each season. When Grimes have been held at 36° F., and then removed to ordinary room temperature (70°-75° F.), they remain in good condition longer than when the storage temperature of the fruit has been 30° or 32° F. Grimes held at the lower temperatures and then removed to a warm room are liable to scald, and appear to become mealy just as soon as the fruit stored at 36° F.

TIME OF DEVELOPMENT OF SOGGY BREAKDOWN ON GRIMES IN STORAGE

In 1925 the development of soggy breakdown was observed from the time of its initial appearance in December until as

TABLE XVII. PROGRESSIVE DEVELOPMENT OF SOGGY BREAKDOWN ON GRIMES, 1925-1926

Lot No.	Storage temperature F.	No. days delayed before storing	Percentage of breakdown			
			Dec. 12	Jan. 11	Feb. 15	May 12
26	30°	0	0	0	2.30	2.30
64	30°	7	0	0.9	16.50	16.50
66	30°	14	4.0	13.6	34.20	34.20
68	30°	21	12.7	28.8	56.30	56.30
40	32°	0	0	0	0.03	0.03
70	32°	7	0	1.7	3.30	3.30
72	32°	14	0.7	4.0	8.90	8.90
74	32°	21	4.3	8.6	29.40	29.40
54	34°	0	0	0	0.15	0.15
76	34°	7	0.9	0	0.61	0.61
78	34°	14	0	0.9	4.50	4.50
80	34°	21	2.5	11.2	11.60	11.60
12	36°	0	0	0	0.00	0.00
58	36°	7	0	0	0.00	0.00
60	36°	14	0	0	0.50	0.50
62	36°	21	0	2.4	2.80	2.80
97	†	0	0	0	0	0
98	†	7	0	0	0	0
99	†	14	0	0	0	0
100	†	21	0	0	0	0

†Air-cooled storage.

late as the middle of May. Its progress was noted at various cold storage temperatures, as well as under air cooled storage. The progressive development of the disease at the end of different periods in storage is shown in table XVII.

It is clearly indicated in this table that soggy breakdown may become of considerable significance before the end of what is considered the normal cold storage season for Grimes. Dealers seldom hold Grimes in cold storage longer than December 20. May not this be due to the development of soggy breakdown?

In January the disease was considerably more severe than in December. At 34° and 36° F., fruit, stored within two weeks after picking, had not developed the disease to any appreciable extent by January 11. On February 15 the trouble had usually increased two to three times over January. However, at 36° F. there was still practically no injury on the fruit that had been stored within two weeks after picking, nor was there practically any injury at 34° F. on fruit stored within one week after picking. No further development took place after February 15 and none had taken place as late as May 12. It is particularly significant that the trouble did not appear under air cooled storage at any time up to May 12. That the disease was controlled or was of little importance at 36° F. as late as February 15 and May 12 is of considerable consequence.

TIME OF DEVELOPMENT OF MEALY BREAKDOWN ON GRIMES IN STORAGE

Soggy breakdown is a disease which may terminate the life of a large proportion of cold storage apples. The disease is practically insignificant when the storage temperature is as high as 36° F. and it makes no development under common storage conditions. However, there is another type of breakdown, termed "internal breakdown" or "physiological decay," which occurs during the senescent stage of the apple. The writers have described the latter as "mealy breakdown."

In 1924 Grimes apples, removed from common storage as late as June 1, showed no evidence of the soggy type of breakdown but displayed all the characteristics of senility or "mealy breakdown." In 1925 the storage life of Grimes was followed carefully from the initial appearance of soggy breakdown in December until mealy breakdown became abundant in common storage by the middle of May. The data in table XVIII show how mealy breakdown developed upon Grimes under different storage treatments, at various intervals, thruout the storage period.

Mealy breakdown was never found abundant in the cold storage lots of fruit before May 15. It became abundant only under common storage treatment late in May. These data show that

TABLE XVIII. PROGRESSIVE DEVELOPMENT OF MEALY BREAKDOWN ON GRIMES, 1925-1926

Lot No.	Storage temperature F.	No. days delayed before storing	Percentage of breakdown			
			Dec. 12	Jan. 11	Feb. 15	May 12
26	30°	0	0	0	0	0
64	30°	7	0	0	0	1.3
66	30°	14	0	0	0	0.5
68	30°	21	0	0	0	0
40	32°	0	0	0	0	0
70	32°	7	0	0	1.9	1.9
72	32°	14	0	0	0	0
74	32°	21	0	0	0	0
54	34°	0	0	0	0.2	0.2
76	34°	7	0	0.9	4.9	4.9
78	34°	14	0	0	5.7	5.7
80	34°	21	0	0	0.6	0.6
12	36°	0	0	0	0	0
58	36°	7	0	0	0	0
60	36°	14	0	0	0	0
62	36°	21	0	0	0	0
97	†	0	--	--	0.1	17.8
98	†	7	--	--	0.6	13.2
99	†	14	--	--	1.2	5.0
100	†	21	--	--	1.2	6.7

†Air-cooled storage.

mealy breakdown is probably not so common in stored fruit as soggy breakdown, which occurs earlier in the season.

Considerable confusion has existed between these two functional disorders, and the term "breakdown" has been used to include both the soggy type and the mealy type. The former can be controlled in certain varieties, at least, by raising the cold storage temperature from 4° to 6° above the usual recommendations, while the latter can almost be disregarded, as it occurs only on overmature fruit, or after a period when Grimes should no longer be in storage. The possibility of increasing the storage period for Grimes, by slightly raising the temperature, deserves particular attention in this connection.

DISCUSSION

A low temperature type of breakdown on apples which occurs at the cold storage temperatures usually employed has been described. This disease, which was previously noted by Plagge (30), the writers believe to be the same as the "internal breakdown" reported in England by Kidd and West (17), and in New Zealand by McClelland and Tiller (26). As the disease occurs prematurely and always at temperatures below a certain level, it is considered different from the breakdown occurring as a result of senility. Altho the disease is somewhat similar to

internal browning reported chiefly on Yellow Newtown as grown in the Pajaro Valley in California, it is not identical.

This type of breakdown has, therefore, been termed "soggy breakdown" in order to distinguish it clearly from the so-called "internal breakdown" or "physiological decay." The writers have also adopted the term "mealy breakdown" for the latter to distinguish it from soggy breakdown.*

Experimental results for three years have shown that soggy breakdown is caused by low storage temperatures, which, however, are not sufficiently low to cause freezing injury. It has been found that Grimes which have been held in common storage houses or at slightly higher temperatures than those usually recommended for cold storage have kept considerably longer than the fruit held at the usual cold storage temperatures. Grimes stored at 34° to 36° F. kept much more satisfactorily with respect to soggy breakdown, eating quality and sale value, and were superior to Grimes stored at 30° and 32° F.

While low temperature was found to be the main causal agent of soggy breakdown, other contributing factors have considerable influence.

Maturity at harvest time and delayed storage at ordinary temperatures have affected the development of the disease. Fruit picked at the beginning of the harvest was found to be more susceptible with delayed storage treatment than when stored immediately; while fruit picked at the close of the harvest season was found to be more susceptible with less delay before storing. Wenatchee district Grimes, which had reached eating maturity when placed into cold storage, became proportionately less susceptible to soggy breakdown as the delayed storage period was lengthened. Grimes from Iowa and Michigan, which had not yet reached an edible maturity, became proportionately more susceptible to the injury as the delayed storage period was lengthened. In another experiment Grimes were stored immediately at 36° F. and held there for four weeks before removal to a room having a temperature of 30° F. In this particular lot more soggy breakdown developed than in either of the check lots, which were stored at 30° and 36° F. continuously. Two other lots, one held at 36° for six weeks and the other for eight weeks at 36° before placing at 30° F., showed a proportionate reduction in soggy breakdown according to the time in storage at 36° F. Apparently apples may become peculiarly susceptible to soggy breakdown when the storage temper-

*Inasmuch as the term "breakdown" has already been applied to the disease, the writers conclude that it is preferable to retain this term. The term "soggy" has been adopted as it denotes the sogginess or sponginess of affected fruit. This also is in contrast to the mealiness of "old age decay" or "mealy breakdown."

ature is lowered below a certain level after periods of exposure to rather high temperatures.

Kidd and West (16) have shown that after an apple is picked the respiratory activity (which previous to picking had reached a minimum) increases very rapidly at ordinary temperatures. This rate of increase continues until a maximum is reached, after which a minimum is again approached. The time required for the respiration rate to rise from the minimum to the maximum is greatly influenced by temperature. Magness and Ballard (21) have shown that a similar condition exists in the case with Bartlett pears held at 59° F. They reported that the respiration rate, as measured by carbon dioxide output, was greatly accelerated from the time the fruit was picked until it became soft yellow ripe.

Burroughs (6) found that Wagener and Wealthy apples, when held at 68.5° F., decreased in the respiration rate after a maximum had been reached. When Wageners had been held at 68.5° F. for three to four weeks after picking, there was a marked decrease in the respiration rate. Magness and Burroughs (19) have shown that the respiration rate of apples at 32° and at 35° F. is very nearly constant thruout the storage season, and that the rate at 35° F. is about one and one-half times the rate at 32° F.

When the Grimes were placed immediately into cold storage at the temperatures of 30°, 32°, 34° and 36° F., soggy breakdown made no significant development during years when the fruit was picked at the beginning of the harvest season. When the fruit was delayed at ordinary orchard temperatures, the same seasons, soggy breakdown appeared abundantly at the two lower temperatures, while it was practically controlled at the two higher temperatures. At 30° F. the amount of the disease present was in proportion to the amount of delay. Apparently the fruit which was delayed went into storage as it was approaching a higher rate of respiration, while that which went into storage immediately was still at a minimum rate. The fruit held at the orchard for several weeks before storage probably reached a high respiration rate and, therefore, as it was placed into storage an abundant supply of certain respiratory products were likely present within the tissues and the internal atmosphere. These respiratory products probably consisted of certain essential oils or other deleterious substances, as well as carbon dioxide. Fruit with presumably high respiratory activity when stored at 36° F., was found to be without injury, while the same fruit when stored at 30° F. became seriously affected.

A feasible explanation as to why the breakdown resulted at the lower temperatures and not at the higher may be the differ-

ences possibly existing in the permeability of the apple tissue at different temperatures. A possible increase in the permeability of the apple tissue stored at 30° F. is suggested as the cause of the injury occurring at this temperature. When there was a change in the permeability or resistance to certain deleterious substances which may have been present within the fruit, browning and breakdown of tissue resulted. This was not the case at 36° F., since, in this case, it is assumed that the permeability of the cells remained at a certain level. However, in searching for the explanation of the cause of soggy breakdown, it should be remembered that the respiratory processes were able to continue at a considerably more rapid rate at 36° F. than at 30° or 32° F. Magness and Ballard (21) have shown that Bartlett pears ripen about twice as rapidly at 37° F. as at 30° F. In their experiments, the writers have noted that the Grimes stored at 36° F. ripened much more rapidly than at 30° or 32° F. This was evident in comparing the color, hardness and eating quality of the fruit at the end of the storage period.

With the fruit picked at the end of the commercial harvest, in 1924, evidently a condition was attained before picking which made the fruit susceptible to soggy breakdown, for the fruit so harvested was found to be affected with soggy breakdown when stored immediately, as well as when given delayed storage treatment. However, this same fruit became more severely affected when it was delayed at the orchard. The time of harvest, then, enters into the consideration of the control of soggy breakdown.

Exposing the surfaces of the fruit to free and forced circulation of the storage room atmosphere gave satisfactory results in preventing soggy breakdown during one storage season. This tends to support the hypothesis that the disease was caused by an accumulation of deleterious substances, with an accompanying increase in cell permeability, since the benefit derived from the air movement was likely that of removing these substances from the apple tissue.

Permitting the fruit to have free access to air by placing it in open slatted crates during the delayed storage period did not reduce susceptibility to soggy breakdown.

The effect of gas absorbents, other than that of commercial oiled paper, on the prevention of soggy breakdown was not tried. Oiled paper gave no better results than unoiled paper in a series of experiments on the control of soggy breakdown.

The development of soggy breakdown in apples appears to be affected by locality, as locality may affect growth and maturity. Grimes from Wenatchee, showing evidence of higher maturity

when stored, developed the disease earlier than the Grimes from Iowa. The disease appeared to develop most severely on the fruit from the Wenatchee region and least severely on Grimes from south central Iowa. However, evidence is insufficient to show that this invariably would be the case. The data do show that the disease may develop on Grimes from various apple regions other than Iowa.

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